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A Conceptual Orientation to the Study of Motor Behavior

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A global model has been developed with special emphasis on cognitive (control) processes that may be operative in the learning and performing of complex motor behaviors. It is most meaningful for instructional and self-learning purposes to determine those processes that may be under the control of the learner, and which strategies are available for him/her to select from. The ultimate intention of this work is to

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facilitate the acquisition of skill, and to encourage learners to use self-managed rather than externally-induced strategies as appropriate to achieve goals with categories of psychomotor tasks. Experimental work and an analysis of cognitive and psychomotor literature will lead to the identification of the best of alternative learner strategies to maximize the internal operations that contribute to effective motor behavior.

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Research and theory associated with motor behaviors have made great strides in contemporary years. Conceptual formulations and research directions reflect a critical analysis of problems and an orderly and systematic approach to resolve them. Much of the work has been focused on either the content of the input, or the reproduction of specific output actions. Several motor behaviorists (e.g., Pew, 1974; Schmidt, 1975) have emphasized the importance of studying the response processes that underlie motor behavior.

As yet, however, research is lacking on the cognitive controls a person may exert over motor behavior. This observation is rather surprising, considering the fact that the learning of complex motor acts involves the activation of a variety of cognitive processes. Those learners who possess many learning strategies and the ability to use the appropriate one or ones at the right time will no doubt have increased the probability of making a correct response.

Therefore, the major focus of our research is oriented to the determination of the relationships among real or hypothesized internal processing mechanisms, cognitive or control processes, and learner strategies (externally and internally generated). We intend to examine these

relationships in various ways to facilitate the learning of motor skills. While previous efforts in the analysis of motor skill learning have been geared to relatively simple tasks which placed minimal demands on a learner's organizational and decision-making capabilities, we believe that the acquisition of complex skills requires a learner to utilize cognitive processes in a more extensive manner than heretofore realized. The identification and the subsequent manipulation of these control processes will enable us to instruct learners to use personal information processing capabilities to develop appropriate strategies for learning and performing a variety of psychomotor activities, in order to be able to problem solve and to adapt to new, but related situations with minimal guidance.

The enumeration of processes which may be under the control of the learner can lead to a more thorough analysis of potential alternative strategies which the learner can employ to meet task demands. In turn, this information can provide a meaningful basis for instruction designed to assist learners in the development and the selection of the best strategies applicable to the acquisition of different types of tasks. Instruction would then proceed at a more rapid pace, and be more economical because the strategies which are most relevant and most effective for the learning of categories of psychomotor tasks have

been determined. Ultimately, the ideal learning environment would be one in which strategies were self-generated by learners rather than externally imposed by instructors.

The identification of alternative learner strategies, along with the cognitive processes a learner may use in conjunction with one or several internal processing mechanisms in a human behaving system must be determined. To accomplish this goal, an extensive, analytical review of the extant literature in the verbal and motor learning areas was conducted. The conclusions drawn from this review will be presented in two reports. In this report, an historical introduction to motor behavior research will be succeeded by a description of the development of a model of the human behaving system which contains specific considerations unique to motor behavior. The model is the result of an effort to integrate research and theory related to information processing, cybernetic, and hierarchical control models, as well as cognitive motivational theory, associationistic theory, individual difference parameters, and other approaches to the study of behavior. The model has been conceptualized to be more global and broadly applicable than the typical information processing models of behavior often reported in the literature. Through this model, we hope to conceive a dynamic and unrestricted view of factors that influence human control processes, and performance outcomes in

general, in addition to those factors that are unique to persons with special learning characteristics, popularly termed "cognitive styles."

The second report will focus on the identification of control processes and strategies a learner may use during motor skill acquisition. Additionally, this report will include taxonomic classification schemes of tasks and strategies, along with a description of the relationship between the categorization systems. In summary, the first report is geared to a description of the development of a model of the human behaving system, and the second report is concerned with strategy identification, development, and implementation.

Brief History of Motor Skills Research

An historical account of the research in motor skills learning would probably begin with Donders' (1868) reaction time studies, with Woodworth's (1899) monograph on the accuracy of voluntary movements, and with Bryan and Harter's (1897, 1899) works on the learning of telegraph language. Since these investigators and others did not actually prescribe a course of action for future researchers in the field, a great diversification of interests and activities followed, leading to much difficulty in defining precisely the domain of motor skills research. Perhaps this was but a natural occurrence, however, since motor behavior can be studied within so many frames of reference

and from a wide assortment of perspectives. It would seem, though, that research dealing with skill acquisition was an offshoot of experimental psychology (Irion, 1969; Schmidt, 1972), especially when one considers the fact that the earliest efforts in skills research were undertaken by experimental psychologists.

Due to the backgrounds of the researchers who were active in the first half of the 20th century, the initial investigations into motor skill acquisition followed the behavioristic school of thought, which was prominent in psychology at that time. This was evidenced by the S-R conditioning techniques used to train subjects and the conceptual notions about behavior. Data were reported in the form of learning curves, in much the same manner as the animal psychologists reported their data. Sophisticated statistical models and methods were to be developed and used in subsequent years, which led to alternative conceptual approaches to the study of behavior and to more elaborate experimental designs.

In the early approaches to skill acquisition, the human organism was viewed as capable of being conditioned to stimuli, similar to the manner in which the animal organism was conditioned. Given enough learning trials, either organism would presumably emit the desired response. The subject was perceived as merely a passive respondent to environmental manipulations in these

experimental situations. However, with the onset of World War II, directions in motor skills research began to change.

At this time, the concern was with the development of those motor skills which could improve national defense, and factors such as pilot training, aircrew selection and performance, gunnery, and submarine control were considered (Miller, 1972). These areas were also to be investigated in the post-war period, as various funding agencies continued to support this line of research (Irion, 1969; Schmidt, 1972). Additionally, interest in skill acquisition was maintained due to the development of Hull's (1943) drive theory of behavior, which was conveniently testable with motor tasks, and by the emergence of engineering psychology, in which the concern was with the design of person-machine systems.

The performance similarities between a person and a machine were emphasized in a theory of information transmission (Shannon & Weaver, 1949). Within this theoretical framework, the capacity of a communication channel (those mechanisms through which information flows) could be quantified and comparisons could be made between the channels. However, communication theory was limited in its applicability (MacKay, 1969) because it did not account for the meaning of the information transmitted in the system. Therefore, Wiener (1954) proposed a

cybernetic theory of behavior in which researchers could study the use of messages to control the actions of humans and computers.

Computers were capable of being programmed to simulate cognitive human behaviors. The study of the transmission of information through the computer, which was depicted in computer programs and flow diagrams, resulted in the identification of corresponding hypothetical mechanisms in the human brain which performed specific functions with regard to the transformation of information (Broadbent, 1958). The acknowledgement that a person actively manipulated information during the acquisition of skill (e.g., Miller, Galanter, & Pribram, 1960) thrust many psychological and educational experimenters toward the study of skills. Internal and personal factors were recognized. Learners, it was realized, played an active role in the learning process, in opposition to the associationistic or behavioristic schools of thought.

The learner's involvement in the skill acquisition process led some researchers concerned with motor skills to utilize tasks in which the learning of the perceptual and the cognitive components was as important as the learning of the motor component. Investigations of motor learning tasks that required cognitive activities received much criticism from strict "motor" behaviorists. Their contention was that the scholarly examination of

motor behavior should be represented by the analysis of movements themselves because skills which required a heavy cognitive involvement on the part of the learner were not _truly_ motor skills. However, complex motor skills _do_ involve thought processes (e.g., a planning component which contains the parameters of a movement, even if it is only the choice of whether or not to move). A few researchers devised tasks in which the subject was required to think, to problem solve (Cratty, 1960), rather than to merely move upon external command. Serial tasks were used by some researchers to investigate the acquisition of motor skill, as were other kinds of tasks in which a reasonably heavy cognitive involvement was necessary for learning.

This small trend in psychomotor research closely followed the strong one in verbal learning research, where psychologists began to investigate the manner in which human learners manipulated, transformed, and utilized information to acquire a skill (Battig, 1975; Estes, 1970; Rigney, 1978 ; Solso, 1973). The resultant "cognitive revolution" in experimental psychology caused many scientists to analyze the role of the learner and cognitive processes during verbal or motor skill acquisition. The major emphasis of the research was on the manner in which a person acquired, maintained, and retained knowledge for future use.

The strategies the learner used to process information to achieve a high skill level became the concern of many verbal and some motor learning theorists. In the motor domain, the primary goal of instruction has been the acquisition and the exhibition of a skilled response. A skilled response is one in which the receptor-effector-feedback processes are highly organized, both spatially and temporally, under conscious or semi-conscious (programmed) control, to fulfill some specified goal. A central problem for the study of skill acquisition, then, is how such organization or patterning comes about (Fitts, 1964). The organization of information pertaining to the learning and performing of motor skills is obviously a function of the cognitive activities in which a person engages.

Contemporary Models of Motor Behavior

One major direction in motor behavior research is currently focused on the cognitive processes a person utilizes to effectively execute skilled activities. How an individual interprets knowledge of results to learn a movement (Newell, 1976), how a person reproduces a particular movement from memory (Adams, 1971, 1976), and how the differential selective attention processes to cues which are utilized as skill level increases are presently under scientific examination. Several conceptual models have been proposed to explain the cognitive

and motoric processes which accompany the acquisition of motor skill (e.g., Bernstein, 1967; Marteniuk, 1976; Pew, 1974; Schmidt, 1975; Welford, 1968; Whiting, 1972). Singer (1975) has extended this work by attempting to identify and to integrate many conceptual approaches to formulate a more global model of motor behavior. He, perhaps more than most, has stressed (1) the importance of understanding the tremendous impact of cognitive processes on the learning and performance of complex motor tasks, and (2) the need to integrate various conceptual approaches to gain a more comprehensive picture of the acquisition of skill.

Singer (1975) has suggested that motor behavior can be described more effectively primarily through a combination of three models: cybernetic, information processing, and adaptive.[1] The unique considerations of each model are important to acknowledge, but it is the <u>integration</u> of the properties of these models which leads to a more complete understanding of motor behavior. Therefore, following a brief explanation of the features of each

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[1]In his book, Singer also alludes to the necessity of incorporating notions from sociology, social learning theory, cognitive motivational theory, and other frames of reference to truly interpret the learning process in general and for individual differences as well.

model will be a description of a newly emerged integrated approach to the study of motor behavior which has been developed in our laboratory.

The learning, adjustment (adaptation), and control of behavior is the result of a hierarchical regulation of performance, which is the major feature of hierarchical control models. Higher order executive programs and lower order subordinate programs are identified as they relate to the cognitive and motor processes necessary to perform a task (Glencross, 1972, 1977; Robb, 1972). For example, a person's perception of task requirements allows the creation of an image or movement plan (executive program) and its execution, including the subroutines associated with it. And, it would appear that perceptual and effector hierarchies can be developed differentially. More skill in complex tasks probably represents the ideal level of both kinds of hierarchies. These subroutines control behaviors which occur either sequentially or hierarchically in order that the performance goal may be reached. With learning, subroutines become integrated into more superordinate routines, and the process continues until the desired skill level is reached. At this time, the original and subsequent executive programs have been relegated to lower levels of control, and the person can perform very complex skills as if automatically.

In order for the subroutines to be adjusted according

to the task and the situational demands, other methods of behavioral control must be established. This can be accomplished through the availability and the correct interpretation of response-produced feedback which accompanies most motor responses (Smith, 1972). Response-produced feedback refers to sensory feedback associated with a movement which informs the central nervous system of the results of its own activity (Konorski, 1967). When feedback is available and analyzed correctly, the learner can compare the present performance with the intended performance, as well as with previous ones. The importance of feedback as a potential control and regulatory system is the major aspect of cybernetic models.

The comparison process enables the learner to use feedback to self-regulate and to self-monitor performance while it is occurring. In self-paced, or closed tasks, the learner formulates the response requirements for the next movement based on the comparison between information just received and information already in long-term storage, thus exerting some degree of control over the situation. As skill level increases, a person depends less on external (other) influences and more on internal (self) control and regulatory processes for the performance of a motor activity. With externally paced, or open tasks, the person becomes more situationally-oriented. Feedback

is also important with these tasks, but so is anticipation and a "correct reading" of changing situational possibilities.

Information processing models, of the three, have most often been applied in a conceptual manner to describe verbal and psychomotor behaviors (Marteniuk, 1976). In verbal learning, proponents of information processing models have influenced the study of human memory and learning through their emphasis on flow diagrams and specific, yet hypothetical memory stores. The functions of central processing mechanisms have been described similarly by several theorists, although their terminology has differed (Atkinson & Shiffrin, 1968; Murdock, 1967; Waugh & Norman, 1965).

The flow of information through the system occurs as stimuli enter an unlimited capacity sensory store. The information may be retained for a brief period of time and transmitted further into the system if the learner attends to specific features of the inputs. Otherwise, the information fades rapidly from the store. Attended information is forwarded to a limited capacity short-term store for maintenance through rehearsal activities. Finally, the information can be transferred to an unlimited capacity long-term store where it is considered to be learned. Thus, the early models of memory were characterized by the transferral of information from store to

store as the information was incorporated deeper into the memory system.

These models served as representations of the learning process. However, it was difficult to explain performance, especially motor performance, within such a framework. Another problem with the initial stage models was the implicit assumption that all information which entered the system <u>had</u> to flow from the sensory store to the short-term store to the long-term store. A similar approach was derived when information processing models were used to describe motor behaviors. Although some of the terminology differed, the basic descriptions were the same.

With regard to motor skills, reference was made to perceptual mechanisms for the selective attention to and perception of relevant stimuli, decision mechanisms which process and place information in short and long-term memory stores and provide commands for the motor act, and effector mechanisms which are activated by these commands to perform the skill. Although these components are essentially identical to those referred to in other information processing models (e.g., Welford, 1968), one major criticism may be levied. Because information processing is only synonymous with information transmission, little provision has been made for the control and regulation of motor behavior. Additionally, the apparent

identity relationship between information processing and information transmission has led to the proposal for new orientations to memory research. A major issue which has developed in cognitive psychology is how memory is to be viewed within an information processing context: either according to depth of processing or in regard to stages of processing.

Multi-store vs. Depth of Processing

In contrast to the present multi-store or stage theory of information processing, Craik and Lockhart (1972) have proposed a unitary, levels of processing model of memory functions. The emphasis in this approach is that the durability of the memory trace is a function of the depth of processing or the amount of meaning applied to the information. More simply stated, the degree to which a stimulus is semantically analyzed is the major determinant of the quality of memory performance. As Craik and Lockhart suggested, the more elaborate the encoding process, the greater the probability of retention.

Recently, Craik (1977) and Craik and Tulving (1976) have revised the original model with the suggestion that it is the degree of stimulus elaboration rather than the depth of processing that is the critical determinant for the establishment of a durable trace. In this view, retention is a function of spread of processing within a particular level or depth and memory can be considered

on a continuum ranging from simple sensory analysis to semantic-associative operations. Additionally, instead of distinguishing between short-term store and long-term memory, Craik and Lockhart (1972) proposed Type I and Type II processing. Type I processing is merely maintenance rehearsal in STS, so that information can be retained beyond the normal decay period. Type II processing involves a deeper analysis of an item which should result in more efficient storage (in our LTS) and thus lead to improved memory performance.

To summarize the levels of processing approach, it can be seen that the learner progresses through a series of hierarchical processing stages, such as an analysis of physical features, a match of input to stored abstractions, and an extraction of meaning. From the ensuing discussion of the activities of the system's human behaving mechanism, it can be easily seen that feature analysis is equivalent to our detection and recognition processes, matching inputs with stored knowledge is similar to our internal representational match within LTS, and the application of meaning is the function of our perceptual mechanism.

It would appear that the levels of processing approach is an extension of stage theory based on a semantic argument, rather than an opposite viewpoint. This contention has been recently supported by Glanzer and

Koppenaal (1977), who employed variations of encoding structures (a standard procedure in levels of processing investigations) in an examination of the serial position curve (standard procedure in stage theory investigation) to separate output performance assigned to LTS and STS respectively (Glanzer, 1972). Utilization of the combined approaches enabled the authors to investigate if the two theories were in conflict through a determination of the effects of encoding instructions upon performances previously associated with the long-term store and short-term store.

Results of the investigation were not supportive of two contrasting approaches. Glanzer and Koppenaal (1977) concluded that a single approach existed, and the difference was only in the semantics of the labeling process (stage vs. level). In a final note, the authors suggested that the levels of processing approach extended rather than replaced the stage model by placing more emphasis upon the encoding and retrieval processes in memory. It would appear that, aside from differences in the labeling of particular mechanisms, both the levels of processing approach and our stage approach are similar in that emphasis is placed upon the central role of cognitive processes and strategies employed by the learner for effective control during skill acquisition and information retrieval. Therefore, a conceptual model

of the human behaving system which is based on the integration of the outstanding features of information processing, hierarchical control, and cybernetic models will be described next.

Need for an Integrative Model

The integration of the primary considerations associated with the three models, as well as with other conceptual approaches, allows for a more global perspective of the human behaving system. Although Singer (1975, 1978) has described this unified system in some detail, recent advancements in the current body of knowledge have resulted in the proposition of a revised model.

To be congruent with the very latest developments in the literature, several refinements of and elaborations upon certain mechanisms and processes identified in the original model have been made in order to propose the most scientifically sound model of motor behavior, with consideration for instructional implications. We have attempted to conceptualize about the type and location of the cognitive processes which may occur in stages and in parallel form during the learning and performance of a motor skill.

The major emphases of the cybernetic, information processing, and adaptive models, as well as other approaches to the study of behavior, are identified in Figure 1. It is interesting to note that specific

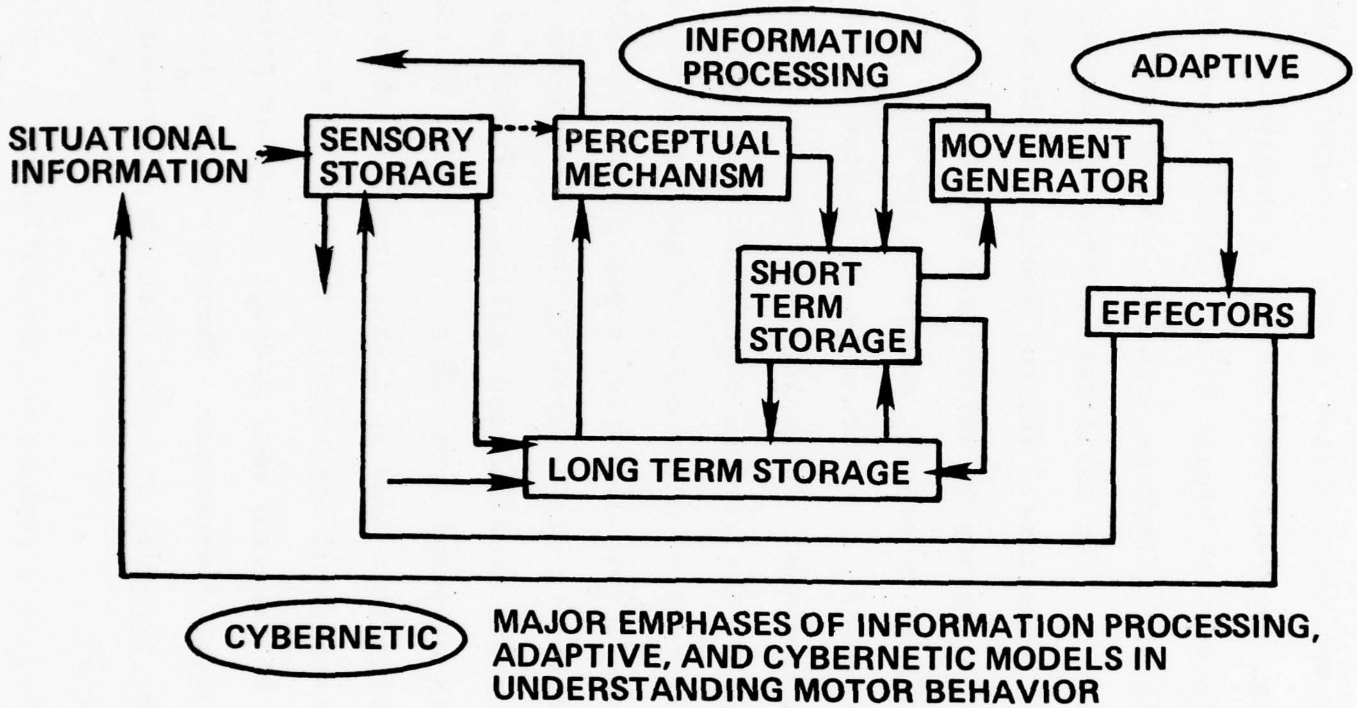


Figure 1
Information Processing, Adaptive, and Cybernetic Considerations of the Human Behaving System

mechanisms in the system can be associated with a particular approach. The features in the proposed model of motor behavior most associated with information processing models are incorporated in the perceptual, short-term storage, and long-term storage mechanisms. The mechanisms associated with hierarchical control models that contribute to the selection, storage, and execution of motor programs are the short-term store, the movement generator, and the effectors. Various sources of feedback are available during or following a motor response, and the emphasis in cybernetic models is how this information from the effectors is returned to the system to be processed for future use. The unique and overlapping major contributions of the various conceptual directions oriented to the study of motor behavior must also be considered with respect to differing capabilities of individuals.

While it might simplify instruction and learning if all persons acquired and utilized information similarly, this is obviously not the case. People possess characteristics that lead to dissimilarities in processing information and behaving in the same situation, and a model of behavior must account for these potential individual differences. Therefore, the previous model must be expanded in order that these considerations are reflected.

Figure 2 emphasizes the influence of culture,

environment, and instruction, as well as developmental considerations, structural and functional capabilities, and emotions, personality, and cognitive style on behavior. This figure is suggestive of categories of primary factors that interact to differentially affect the learning of motor skills by individuals.

Differential behaviors associated with various personal characteristics will not be analyzed here. Instead, a general conceptual model of motor behavior will be proposed and described in some depth (Figure 1 will be elaborated upon). The model will be used as a framework for the study of the sequential stages of processing information which occur from the receipt of stimuli to the exhibition of purposeful motor behavior. A clearer understanding of the cognitive processes any learner employs to become proficient at a motor task can be obtained through the identification and the explanation of the association between the control of information transmission and the hypothesized stages in the model.

A Conceptual Model of Motor Behavior

The human organism, as an active processor of information, continuously interacts with a transient environment. The stimulation of the various sense receptors (e.g., auditory, visual, kinesthetic, tactile) by

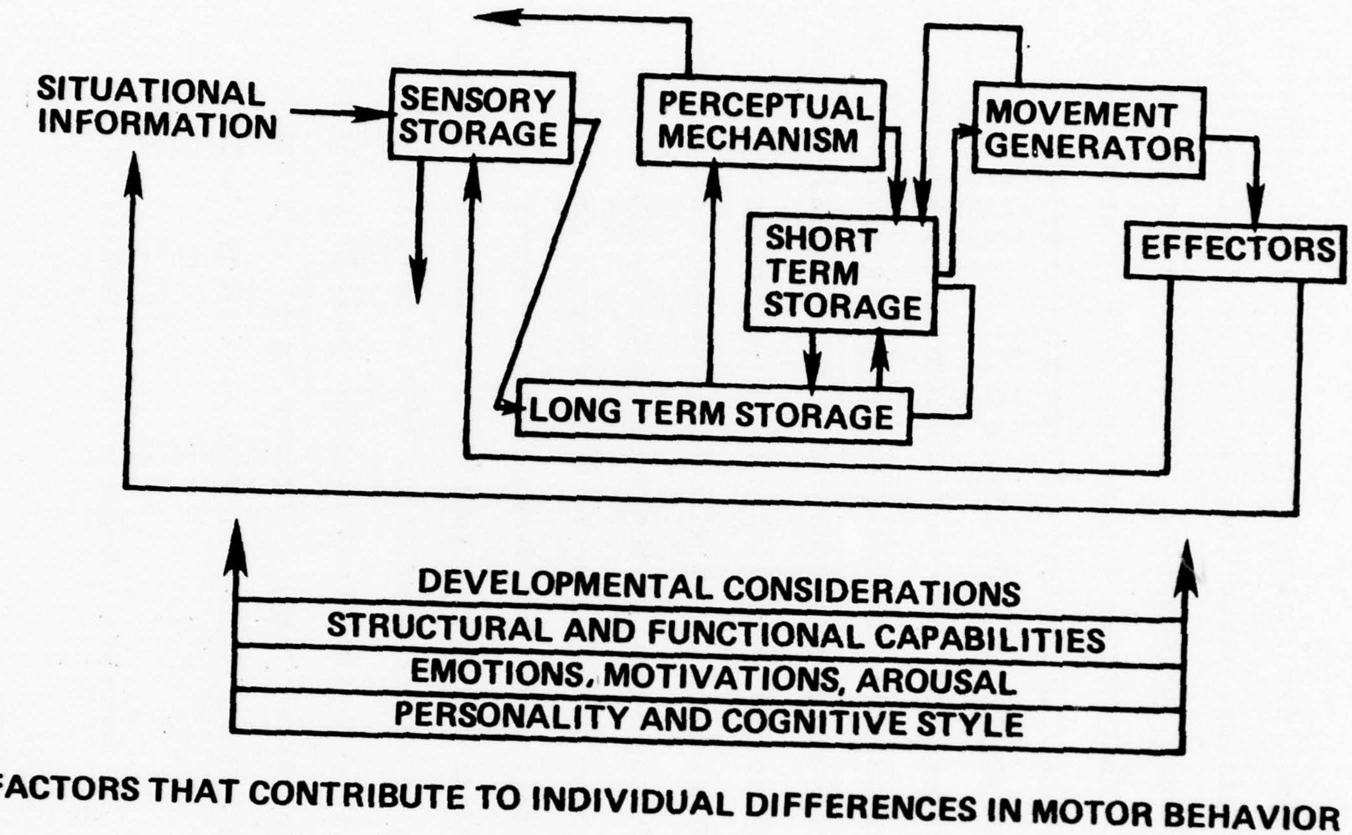


Figure 2
The Effect of Individual Differences
on the Human Behaving System

environmental or organismic cues renders the human behaving system functionally operative. The activation of the system is evidenced in a series of transformations which ultimately results in a conversion of the stimulus input into a selected, observable response. Although the previous diagrams of the model may lead one to view the human behaving system as a rather simplistic means-ends construct, with the implication that incoming stimuli pass uncontrolled from one mechanism to another, the ensuing description of the mechanisms and their associated cognitive processes will serve to illustrate the intricacies involved in the processing of information during skill acquisition.

Sensory Store

Any behaving system becomes activated and functionally operative when sense receptors are stimulated by environmental and/or organismic cues which become briefly stored as internal representations of the impinging stimulus field (Sperling, 1960). The information from the display or situation is briefly stored, along with information from the organism's own efforts, in the sensory stores.
In Figure 3, it is shown how these two sources of information impinge upon sensory mechanisms to be stored for a brief period of time. The organism conducts a preattentive analysis (Neisser, 1967), which results in some stimuli which are below threshold being unattended and fading from the system, while other inputs which are

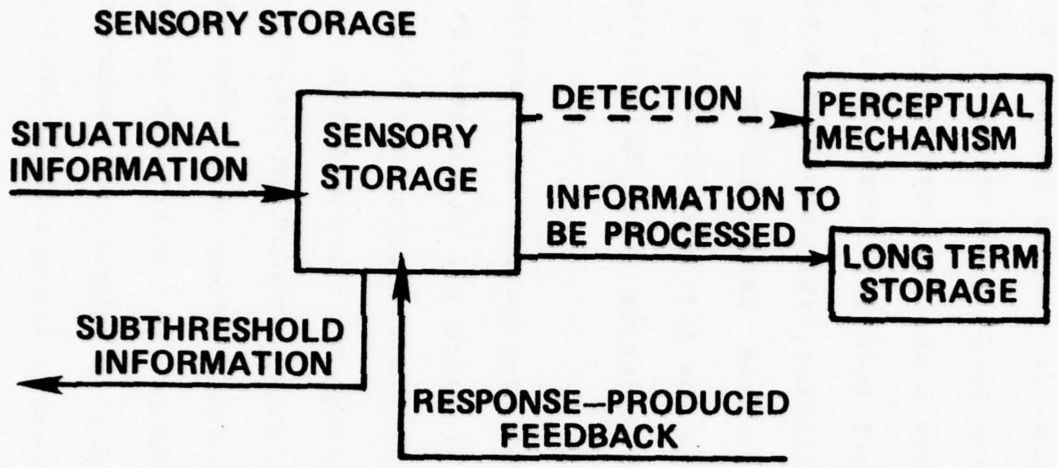


Figure 3
Activation of the Human Behaving System by Information Reaching the Sensory Register

above threshold are made ready for processing. This preprocessed information, as we term it, is transmitted forward to the long-term store to make memory contact with previously stored, similar, internal representations. The mechanism functions as a repository that accepts inputs of the display without regard to feature differentiation, in a manner equivalent to the role of Broadbent's (1971) short-term sensory store. The receipt of inputs can be thought of as analogous to a vacuum cleaner which ingests all objects in its path, impervious to article distinction.

The arrival of environmental cues into the sensory stores prompts the learner to conduct a preattentive or precategorical analysis (Neisser, 1967). Although Neisser suggested that the preattentive process involves discriminations based upon relatively crude physical distinctions (e.g., location, shape, size), more recently, Shiffrin and Schneider (1977) have emphasized the importance of previous experience (acquired through training and/or practice) as a mediator of the preattentive process.

While there is agreement that previous experience indeed affects the discrimination of incoming stimuli at the initial stage of processing, such differentiation is not necessarily guided by the learner's intentions

(Kahneman, 1973). Rather, the inputs are guided by physical characteristics (e.g., size, shape, location). Since differentiation appears to be a more advanced form of processing, it cannot occur in the sensory store because of the repository nature of that mechanism. Differentiation can only occur after the inputs are transmitted further into the system. As such, stimuli below the organism's threshold allow no immediate interpretation within the given situational context and stimuli exit or fade from the sensory store unattended. Stimuli which are above threshold are transmitted into the system for further processing in relation to previous experience and/or salience. As can be seen in Figure 1, stimuli may be transmitted from the sensory storage to either long-term store or directly to the perceptual mechanism. The specific pathways of the stimuli are contingent upon a distinction between detection and/or recognition of the incoming signal. Detection is the process by which the human behaving system becomes aware that a new stimulus has been received without meaning being applied to that stimulus. Thus, it is detection that may initiate the first of multiple transformational processes which will ultimately lead to the selection of a response by the organism (Massaro, 1975).

The determination that a change has taken place in the environment does not always necessitate that the

specific stimulus be recognized. In this sense, "specific memory for a stimulus need not be involved at all in this process" (Massaro, 1975, p. 292). For example, in a crowded room amid numerous conversations, an individual may hear a sound (signal) which does not match the environmental noise. Although the sound is too faint to be recognized, the individual can still be said to have "detected" that signal. As illustrated in Figure 1, a particular stimulus may be detected without contacting long-term store for recognition purposes, and the stimulus may then proceed onward to the perceptual mechanism. In essence, there can be detection without the process of recognition.

To summarize, the sensory store serves two functions within the human behaving system: (1) it receives incoming stimuli, storing it briefly; and (2) it transmits the stimuli immediately to the perceptual mechanism or to the long-term store for memory contact.

<u>Long-Term Store</u>

Although stimulus cues impinge upon the sensory stores, the inputs have not yet acquired meaning within the context of the particular situation.

> Immediate access to a starting location in the memory can tell us whether we have knowledge of the topic or input signal: it cannot tell us the full interpretation of the input. (Norman, 1973, p. 411)

Therefore, "preprocessed information," as we term it, must be transmitted to the long-term store to activate memory contact with previously stored, similar representations. In addition to the arrival of external inputs, the organism provides internal cues representative of developmental characteristics, structural and functional capabilities, present arousal state, thoughts, personality factors, and individual cognitive style (see Figure 4).

In contrast to this viewpoint, numerous proponents of information processing models (e.g., Broadbent, 1971; Kahneman, 1973; Treisman, 1960, 1964; Welford, 1968) have negated the role of LTS in the *preliminary* recognition process. However, it would appear that the access and structure of memory must be based upon sensory signals if recognition is to occur (Norman, 1973). If the contention was not plausible, how else would the organism know immediately what it didn't know? The suggestion here is that the incoming sensory signals contact LTS and are internalized in the form of a representation which achieves access to the memory structure (Atkinson & Shiffrin, 1968; Atkinson & Wickens, 1971). Similarly, Simon (1976) has concluded that there already exists information in LTS (acquired through experience) which permits the identification

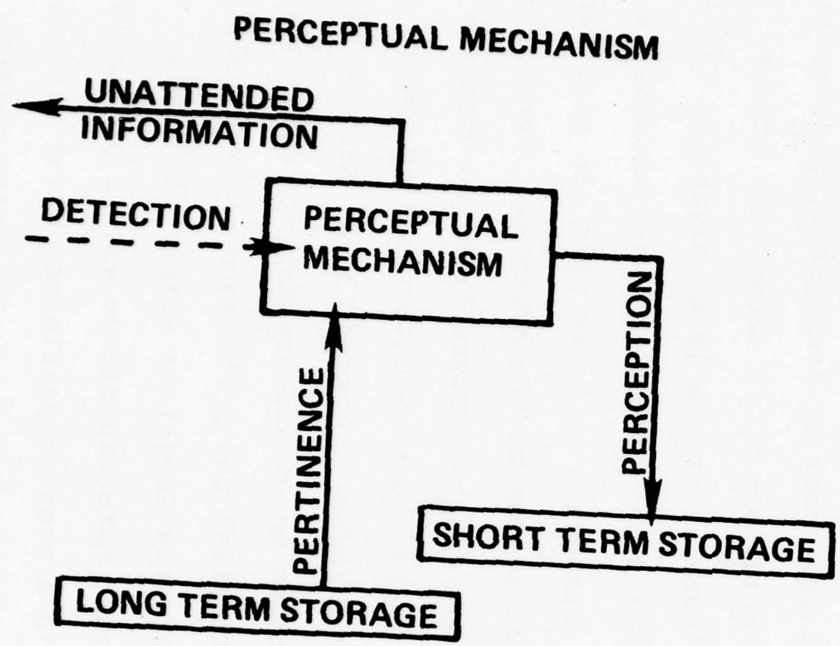


Figure 4
Long-Term Storage as a Mechanism which Provides Pertinence Levels, Referents, and a Storage Space for Information

of incoming stimuli. These interpretations lend particular credence to our contention that the neurological code momentarily stored in the sensory register must be transmitted to long-term store where it can be matched with previously stored representations.

It is conceivable that while all past events may reside in long-term store, the organism places differential importance upon the knowledge with respect to variables such as recency and frequency of occurrence, and familiarity. The internal representations which occupy the memory structure can be viewed as stored in an organized fashion, with the most salient events being the most accessible. The organizational structure is based upon the pertinence value allotted to each item by the organism. The significance of pertinence can be derived from two distinct sources such as stimulus identification and an analysis of previous inputs (Lindsay & Norman, 1977; Norman, 1968, 1976). Previous experiences and present stimulus inputs are combined to establish the pertinence value of all "items" that contact the long-term store. It would logically follow that more experience with a particular stimulus results in a greater pertinence value assigned to that stimulus. Illustrative of this point is that fact that individuals, regardless of specific attentional demands, react instantly upon hearing their name (Cherry, 1953). The cocktail party phenomenon has been offered

as evidence that items which are frequently experienced (e.g., individuals' names), or items which are very familiar, achieve higher pertinence levels within the long-term store which facilitates access to the perceptual mechanism. The facilitatory process has been termed "automatic processing" (Shiffrin & Schneider, 1977).

An automatic process can be defined as parallel pathways of information transmission through the cortical centers that become activated in response to a particular well-learned stimulus and that require little or no conscious attention on the part of the learner. The initiation and subsequent completion of the automatic process, whether externally or internally generated, is contingent upon the strength of the initial input (Schneider & Shiffrin, 1977). The suggestion is that the greater the potential pertinence value derived from the stimulus which contacts memory the greater the probability that an automatic process will be initiated by the learner. Additionally, it appears that detection, as we described it, is also an automatic process within the human behaving system as evidenced by the fact that automatic processing does not require much active control or attention by the learner (Shiffrin & Schneider, 1977).

The implementation of a subconscious automatic process enables the organism to immediately activate representations in LTS similar to the stimulus input

(LaBerge, 1973, 1975; Norman, 1976). However, it is implausible to suggest that the human behaving system is capable of automatically matching all inputs to their internal representations. Supportive examples of this position are investigations that dealt with memory recall and recognition tasks (LaBerge, 1973, 1976; Shiffrin & Schneider, 1977). In those studies, target words and distractor words were interchanged during various trials. Obvious lags in the amount of processing time needed when specific words (memory sets) were not held constant across trials were evidenced in the results. Thus, subjects were forced to spend additional search time to match the "new" target word with its internal representation. The implication is that a need exists for a second type of processing which enables the organism to actively control transmission of inputs through the system.

Controlled processing or controlled search is a description of a learner's utilization of a temporary sequence of cognitive activities which may be invoked to facilitate the transmission of information through the human behaving system. Unlike automatic processing, a controlled search is highly demanding of attentional capacity, is serial in nature with a limited comparison rate, and is probably amenable to alteration or learning (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977).

The advantage for a learner to engage in controlled processing rather than automatic processing is that the learner has greater adaptability to novel situations through sequential processing because more cognitive control is exerted in the situation. Thus, there are some situations where an automatic detection process may best suit the learner's needs, while at other times, a controlled search would be more desirable.

The activation of either an automatic or controlled process based on contact with LTS is dependent upon the pertinence value (e.g., previous experience) assigned to the incoming stimuli. The higher the pertinence level of an item, the greater the probability that it will be processed automatically, or detected, without the necessity of conscious control. Contrarily, the lower the pertinence value, the more likely the learner is to invoke a controlled process activation of the LTS. It may be concluded that pertinence value as well as the particular information expectancies derived from the confirmation of previously experienced inputs of similar situations (Hochberg, 1970; Norman, 1968) will determine whether an automatic or a controlled process is initiated by the learner.

In Figure 3, it can be seen that information in the sensory store may be detected and <u>automatically</u> transmitted to the perceptual mechanism, while other

information, termed preprocessed, is forwarded to the LTS to make memory contact and to be assigned a pertinence value for controlled transmission to the perceptual mechanism where recognition will occur.

Thus, the function of the LTS can be dichotomized into the provision of a pertinence value to information which contacts memory so that the information may be recognized in the perceptual mechanism, and a storage space for information which is transmitted from the STS for learning. In this sense, the LTS preserves the modified internal representation of the information for future use. This latter function will be discussed more fully following a description of the role of feedback.

Perceptual Mechanism

The detection process, and the level of pertinence, or information expectancy set, alerts the perceptual mechanism to anticipate the order of arrival of specific information (see Figure 5). The sequential arrival of information enables the organism to selectively attend to the most relevant inputs, usually those stimuli which enter the perceptual mechanism first. However, while the pertinence items have acquired relevancy through contact with LTS, they have not yet gained meaning within the context of the present situation. Therefore, the perceptual mechanism must continue to recognize the present cues so that the information may be rendered meaningful.

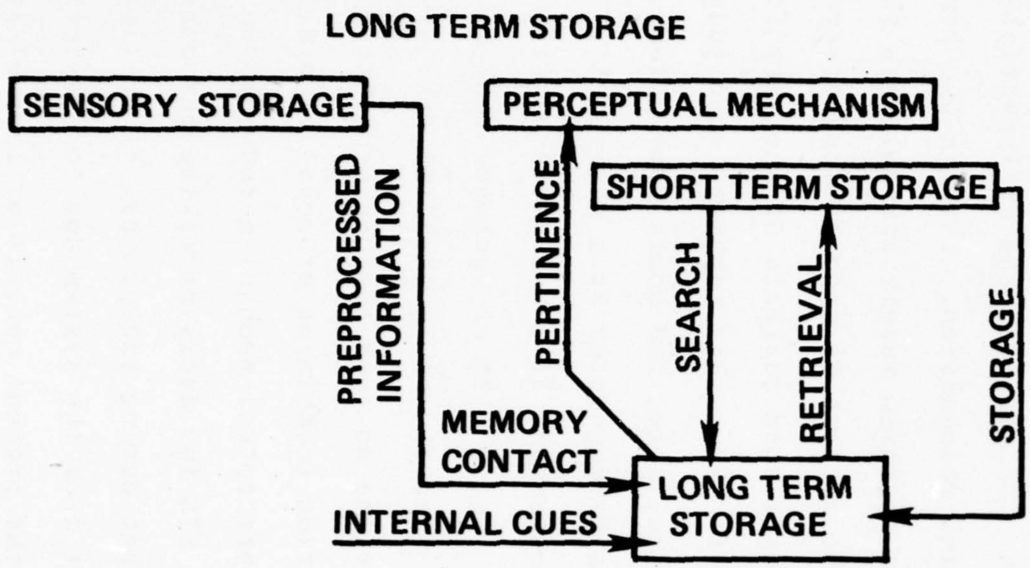


Figure 5
The Perceptual Mechanism Provides More Meaning to Situation and Tasks After Receiving Information with Pertinence Value from the Long-Term Storage Preprocessed Information from the Sensory Storage

The application of meaning to stimuli can be viewed as the unitization of similar features into patterns of recognition (Estes, 1970; LaBerge, 1976). For example, the sensory features of a human face or a word may have contacted individual representations in LTS (e.g., nose, eyes, ears). The identification of the features as a face, however, requires the analysis and subsequent consolidation of the individual characteristics into one recognizable unit. Herein lies the differentiation between detection and recognition. Through the process of detection, the organism merely acknowledges the existence of an object. The process of recognition, however, requires a more complicated analysis of the specific features leading to the rather sophisticated judgement that the eyes, ears, nose, and mouth form a face. It is the face which is "recognized" as a whole unit. As LaBerge (1975) contended, if these patterns were transmitted to STS as just a list of features that were processed either serially or in parallel, the system would have to operate on each feature separately.

The unitization (combining process) of similar features in the perceptual mechanism reduces the number of items sent to STS for decision-making purposes. It is conceivable that during the process of unitization, items may be lost from the system due to dissimilar features within the present context or lack of attention

by the organism (LaBerge, 1975). Similarly, the detection of a signal may not necessitate a response on the part of the organism. Thus signals which are detected, but not acted upon, also exit from the human behaving system's perceptual mechanism.

In marked contrast to the view that a functional perceptual mechanism exists within a behaving system, numerous information-processing theorists have excluded a perceptual mechanism from their models (e.g., Broadbent, 1971; Deutsch & Deutsch, 1963; Shiffrin, 1976; Shiffrin & Schneider, 1977). Designers of these models have allocated the processes which underlie a perceptual mechanism to either the sensory mechanism (Broadbent, 1971) or to the short-term store (Shiffrin, 1976; Shiffrin & Schneider, 1977), or to an attentional mechanism (Kahneman, 1973). The general viewpoint has been that an attention mechanism or filter (Broadbent, 1971; Deutsch & Deutsch, 1963; Treisman, 1964) becomes activated directly after information passes through the sensory stores. The purpose of the filter is to isolate relevant from irrelevant information and to only allow the relevant information to receive continued processing through access to memory stores. The major deficiency in the early filter theories was that only one stimulus could proceed through the processing channel at a time (Welford, 1968). This led to two theoretical departures from the early single-

channel position.

Treisman (1964) proposed that a signal would be attenuated, rather than being completely filtered out. The attenuation process results in some "leakage" of information to the memory system, where a response can eventually occur. With the attention mechanism still placed between the sensory and memory stores, Treisman had difficulty in explaining how some signals could achieve parallel access to the memory system. To account for this phenomenon, it was proposed that selectivity, or filtering, occurred at the memory level instead of the sensory level (Deutsch & Deutsch, 1963; Norman, 1968).

Perhaps it is too impossible a task to determine a specific location point for attention. Instead, attention may be viewed as influencing all information processing behaviors, from decisions on which information to focus, to decisions about what aspects of the inputs should be rehearsed. The concept of attention and its relation to memory processes may very well be the central issue in cognitive psychology. It is not suggested here that an attentional mechanism does not exist. Conversely, we believe that attention is such a pervasive behavioral phenomenon that it cannot be located within one hypothetical structure in the human behaving system. We propose, therefore, that a perceptual mechanism, located at the beginning of the system, can control the process of

selective attention, which is a subsidiary of all attentional behavior. Furthermore, it is our contention that, beyond a simple detection process, selective attention in the perceptual mechanism before LTS contact is impossible because the representations have not yet acquired contextual or situational meaning, and without meaning, a learner cannot know which information is relevant.

There is, however, a contrasting opinion. Shiffrin and Schneider (1977) suggested that the short term store simultaneously functions as organizer, analyzer, and appraiser of incoming information. To assign all these functions to the STS would appear to negate the widely accepted notion of limited capacity and rapid decay associated with short term store. Thus, there would appear to be a necessity for the inclusion of a perceptual mechanism within the human behaving system.

Upon completion of the perceptual process, the human behaving system has analyzed the relevant features, consolidated these features into recognizable units, and applied meaning to the incoming information. It is the combined result of these activities that stimulates the transmission of information to short-term store, where a decision about the course of action will be made.

Short Term Store: Parameters and Processes

The short-term store (STS) (see Figure 6) is the most significant mechanism in the human behaving system since

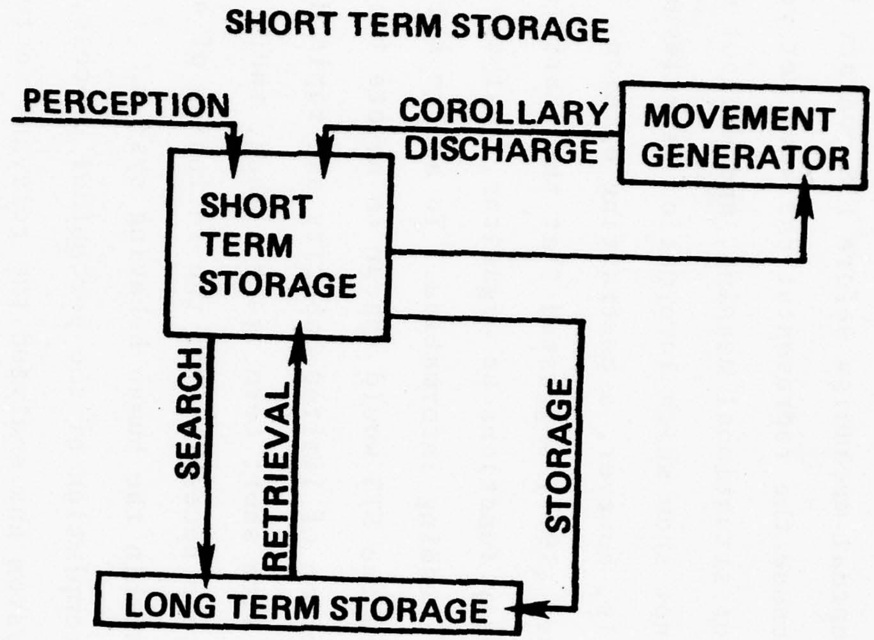


Figure 6
The Activities of the Short-Term Store

all the mechanisms transmit information to STS for rehearsal, organization and decision making. The mechanism, in turn, transfers this information to LTS for learning to occur. Upon completion of a movement, the response outcome is transmitted through the sensory storage and the LTS, and then back to STS where error correction can occur. It would appear from this rather global description that the processing capacity of STS is limitless, but we do not suggest this at all. Results of investigations into the area of immediate recall (auditory and visual) have consistently been supportive of the organism's inability to process numerous, differential stimuli concommitantly (e.g., Massaro, Cohen, & Idson, 1976; Shiffrin & Schneider, 1977; Sperling, 1960; Treisman, 1964). The capacity limit of STS, then, has a strict upper limit based upon the complexity and quantity of the information that can be handled within the mechanism (cf. Miller, 1956). It will be beneficial at this point to discuss the parameters within which STS operates as well as the processes carried out by the mechanism.

The memory structure of STS serves three distinct functions within the human behaving system. First, STS furnishes the learner with a temporary storage area ("working memory") for information currently important to the organism. Second, STS is responsible for a majority of the decision-making, problem solving, and thinking

behaviors of the human organism. Third, STS integrates the first two functions to determine that information which is transferred to long-term storage. These functions are carried out based on the storage capacity of the mechanism. Miller (1956) proposed the amount of information that can be stored in STS was contingent upon the familiarity of the items. In this sense, the less familiar items would require additional time and space for processing to take place. As such, and with respect for differences in individual processing capabilities, Miller (1956) quantified the amount of information held in STS as being 7 ± 2 chunks (units of information). Thus, individuals were viewed as being able to handle as few as five or as many as nine units of information at one time, although these numbers have been shown to vary (e.g., Glanzer, 1972).

The differences in processing capacity among individuals are not due to structural deficiencies (Chi, 1976). Rather, differences in functional capabilities of the short-term store are the causes of performance differences. This functional deficit has been related to inexperience in strategy usage (Brown, in press; Chi, 1976) across age groups. Although mature learners show greater processing ability due to a more sophisticated use of strategies than their less mature counterparts, performance differences due to an inability to apply appropriate strategies have

also been evidenced by learners who differed only in their level of experience with the material to be learned (Brown, in press). It can be concluded that the functional capability, and therefore the available processing capacity, has a direct relationship with the type of strategy the learner invokes to acquire information.

Through the use of various learner strategies, incoming information is transformed into more organized units which allows additional processing space to become functional (Chi, 1976; Dansereau, 1978). The more automatic the sequence becomes, the less need there is for the learner to consciously attend to the process. A decreased necessity for conscious control by the organism frees the system so that the learner is able to process input cues while simultaneously working on information already in the mechanism. Within this context, the efficiency of a continuation of automatic processing from LTS is apparent. As situations become more familiar or redundant, a simple repetitive sequencing of the processing operations is all that is required.

Although familiar information may be processed automatically and directly transferred to the LTS, less familiar information must be rehearsed in the STS. A major function of the STS during rehearsal is to provide greater meaning to the inputs so this information may

be easily transferred to the LTS. Perhaps the most efficient method of information transfer a learner would use may involve organizational strategies to recode information, or to transform it so that it can be incorporated within a previously established stable internal code.

The provision of an organizational structure to information in the STS results in a greater learning of that material, because the information is now more meaningful. The transfer of the learned items from the STS to the LTS proceeds rather easily at this point as the present material has been related to and grouped with stored knowledge. The reconstruction of newer, more meaningful chunks of information leads to the inference that memory function between mechanisms is an interactive process. While the functions can be described independently, it is the interaction of the functions that leads to effective behavior. Thus, while the major function of the LTS is as a storage unit, the interactive nature of memory is exemplified by the extraction of information from and the transference of information to the LTS. This process is necessary for the STS to conduct all of its active processing operations.

In addition to serving as the mechanism in which a majority of the processing of information occurs, STS also functions as the mechanism in which decisions are

made about movement selection and execution. The decision process requires the retrieval of information from LTS, a comparison of this information with the learner's present knowledge of the surrounding environment, a knowledge of the goal to be achieved, and finally, the selection of an appropriate motor program which can be used to control the upcoming movement. It is this decision-making process for motor program selection and movement generation which uniquely distinguishes the model of the human behaving system from other models of memory and behavior.

Motor Program Selection

A motor program is a predetermined set of neural commands which controls muscular activity (Klapp, 1976). The uniqueness of the motor program lies in the fact that the response is structured before the movement sequence begins (Keele, 1968). The execution of the movement is often dependent upon the present environmental conditions (Gentile, 1972), so that it is not always the availability of certain programs which prescribe the movement to be executed, rather, it is the situational context within which the movement must be performed that influences program selection by the STS based on information extracted from the LTS. There is justification, then, for the STS to receive ordered and meaningful inputs which convey information about the relationship of the organism to the current state of the environment

from the perceptual mechanism, as well as to search and to retrieve from the LTS any previous knowledge that pertains to a particular situation. Once these sources of information have been integrated, the STS selects the appropriate motor program to achieve the desired goal.

At this stage of processing, the person must search long-term store for the appropriate motor program which best matches the environmental conditions and the demands of the skill to be performed. While there is intuitive appeal to assume that a perfect match between previous experience (learned motor programs) and present conditions (perceived information) can be obtained, this does not often occur. Recent biomechanical and electromyographical analyses of movement sequences have led to the conclusion that individuals do not execute movements in identical fashions each time the movement occurs (e.g., Higgins & Spaeth, 1972). Similarly, Bartlett (1932) has stated that a movement is never performed twice in the same way. Therefore, to produce an effective movement, the problem which the learner must overcome is how to modify a stored motor program so that previous response specifications can be adapted to meet the demands of the present task.

The specifications or the parameters of the motor program that a person will use must account for variables such as speed of movement, terminal location of the movement, distance to be moved, force and timing of the

movement, and the effort required to execute the movement properly. Klapp (1977) has provided some recent evidence in which the suggestion has been made that these response programming variables occur independently of the muscles that are chosen to effect the response. It is not our purpose here to determine if response programming and muscle selection occur separately, but it should be noted that if these two stages are independent, the latency of the decision process for movement must increase.

The cognitive processes a person uses to reach a movement decision are also shown in Figure 6. The operations of search and retrieval of information from the LTS, and the modification of a stored motor program in the STS are essential to produce a goal-directed movement. Once the motor plan has been decided upon, the STS transmits the results of the decision to the LTS where the information can be stored for future use. Simultaneously, the STS transmits the motor program to the movement generator, where it is loaded in preparation for the movement to occur.

Movement Generator

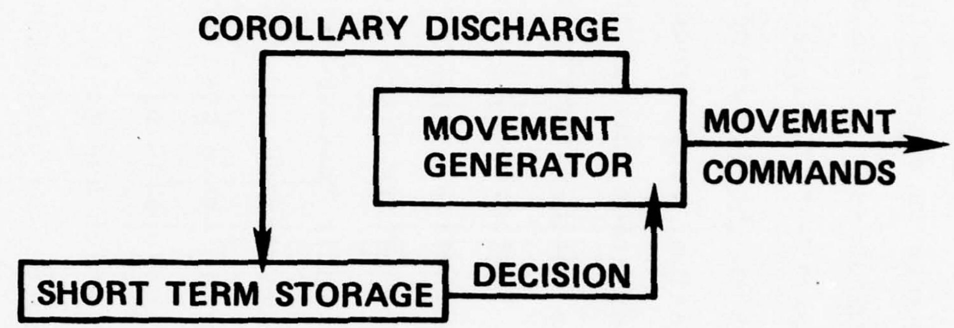
While it can be expected that at least one motor program will be selected by the STS and entered into the movement generator to control a discrete movement, it is incorrect to assume that a single program would be capable of regulating a sequence of responses. The exact

duration of a program is unknown, but there is evidence to support the contention that several motor programs can be called up to control a sequence of movements (Shapiro, 1976). This conclusion served as the basis for Klapp's (1976) contention that several motor programs can be loaded at one time into an output mechanism (movement generator) to effect a series of movements. Upon completion of the loading process, the person must organize and initiate the programs in the appropriate order to achieve the movement goal.

The loading and the organization of the sequence of motor programs in the movement generator symbolizes the completion of the response programming stage of movement. The motor plans are merely abstract representations of the intended goal of the movement (Klapp, 1977). Therefore, it is necessary for the movement generator to select the appropriate musculature to perform the activity. When the muscle group or groups that can best achieve the goal have been determined, the generator mechanism initiates the motor program or programs through the transmission of a sequence of efferent neural commands to the chosen muscles to cue them to perform the response (Keele & Summers, 1976). Simultaneously, the movement generator emits a feedforward signal, corollary discharge, to the short-term store to prepare the system for the sensory consequences of the

forthcoming motor act. These processes are illustrated in Figure 7.

Corollary discharge is essentially a "carbon copy" of the efferent commands sent to the effector mechanism. In addition, the corollary discharge serves much the same function for the STS as the pertinence value serves for the perceptual mechanism. Both processes facilitate the transmission of information through the human behaving system, based on the anticipation of the arrival of particular inputs. Furthermore, although pertinence value is only a hypothetical psychological construct, the existence of a corollary discharge, though not firmly established, has recently received strong support from investigations of preselected and constrained movements. Results of these studies have been almost unequivocal. When blindfolded individuals initiated volitional movements (preselected) which had to be replicated, considerable enhancement of reproduction performance occurred relative to conditions where individuals moved to an externally determined end point (constrained) (cf. Gerson, Note 1; Kelso, 1977; Kelso & Stelmach, 1976; Marteniuk, 1973). The performance differences were attributed to the corollary discharge associated with the production of an active, voluntary movement, thus providing some support for the existence of this neuropsychological process.



MOVEMENT GENERATOR

Figure 7
The Movement Generator as it Operates
to Produce a Motor Response

For corollary discharge to be beneficial to a learner, the muscle selection process based on the loaded motor programs must be carried out. If muscle selection and response programming (STS) are independent processes (Klapp, 1977), there is a need for a mechanism in the human behaving system to carry out the muscle selection process. It is proposed that a movement generator exists to execute this function. Therefore, the movement generator not only loads, stores, and organizes selected motor programs, but it also determines which efferent impulses are discharged to a particular muscle or muscle group.

Effectors

Although Marteniuk (1976) has combined the processes of the movement generator and the effectors into a unitary effector mechanism, it is proposed here that effectors exist within the human behaving system, distinct from the movement generator (see Figure 8). Effector mechanisms consist of the muscles which control the limbs that produce the desired response. Once the muscle selection process has been completed in the movement generator, the effector mechanism executes the movement in the proper sequence. The execution of the movement leads to response produced feedback, as indicated in Figure 8.

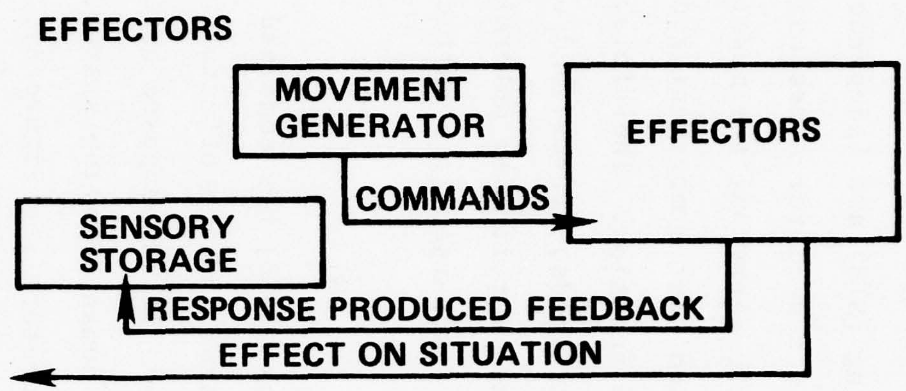


Figure 8
The Effectors and the Transmission of Feedback
through the Behaving System

The Role of Feedback

Feedback is any response-produced information a person may receive through the various sense receptors due to his or her own efforts. When it is provided through an external source, such as an instructor, it is referred to as augmented or supplementary feedback. As an example, a person who shoots a ball at a basket receives kinesthetic feedback associated with the execution of the response, as well as visual feedback about the outcome of the response. Thus, feedback is informational in regard to the "feel" of the movement, as well as to situational changes that occur due to the movement. Either source of outcome information is usually available without being supplied by an external source. Should outcome information be provided for the learner, it would be transmitted through the human system in the same way as any other environmental information. These processes are illustrated in Figure 8, where response-produced feedback enters directly into the sensory stores, and feedback due to the effect of behavior on the environment may be considered as situation outcome feedback. This information, although not externally supplied, also enters the sensory stores from the environmental display.

Regardless of how feedback enters the system, either intrinsically or extrinsically, the information flows

through the system in much the same way as any other stimuli. The difference between the processing of feedback and the processing of any other inputs that may enter the system at this time is that the corollary discharge has alerted the cortical centers of the brain to anticipate the arrival of the response-produced information. The anticipatory state prompts the learner to activate a search of the LTS for a specific portion of the knowledge base (i.e., the movement goal) that should match the feedback. Thus, when the feedback contacts memory, the pertinence value of the response-produced information will be high, which leads to the rapid transmission of that information from the LTS through the perceptual mechanism to the short-term store.

One point must be clarified. Feedback information must contact the LTS and be recognized in the perceptual mechanism to be rendered meaningful, before it is transmitted to the short-term store. A simple detection process is necessary, but not sufficient for the feedback to be utilized by the system, because detection does not involve a comparison with stored referents. Feedback can only be used to determine the existence of an error when there is a standard to which the feedback can be compared. Additionally, feedback can only become meaningful after it has been detected and recognized, at which time the processes of error detection,

error correction, and learning begin to occur.

The processes of error detection and error correction occur within the short-term store. The learner interprets the feedback information and extrapolates what modifications, if any, are necessary in the motor program so that future performances may achieve the goal. The change in the response specifications of the program is transferred to the LTS, along with information about the current state of the environment. The stored knowledge will then serve as a referent for future performances.

Concurrently with the transfer of information related to the movement decision from the STS to the LTS, the learner adapts upcoming responses based on the correction of errors. The modified motor program is then determined, and the movement plan is transmitted to the movement generator in the same manner as the initial program information was loaded. When the response is run off, feedback is again sent through the system to continuously update the referent of the correct movement. The process continues until there is little or no discrepancy between actual and intended performance, at which time the information in the STS is placed into the LTS for permanent storage. It is at this time that learning has occurred.

Learning occurs through the use of two types of feedback. The performance of a slow, graded response enables a learner to detect and to correct errors which

may occur during the response through the use of continuous feedback. The learner utilizes this form of response-produced information to modify activities while they are being performed. The response occurs slowly enough to allow the available feedback to be attended to and processed before the motor act has been completed.

In contrast, certain motor skills are performed too rapidly for feedback to be attended to and processed during the activity. Although feedback is available throughout the performance of these ballistic movements (those movements that occur in approximately 200 msec or less), the learner is unable to use response-produced information until the termination of the movement because of processing delays associated with information transmission (see Keele, 1968, 1973, and Schmidt, 1975, 1976 for reviews). The learner than uses terminal feedback information for error detection and error correction similarly to the manner in which continuous feedback information functions.

Both types of response-produced information are used to upgrade performances. The difference between the two is the availability of each type during the acquisition of a motor skill. Learners must be taught an awareness of which feedback information is most appropriate for a particular motor skill so that attention may be properly directed for the feedback to be correctly interpreted and

functional. However, feedback is not only available for error detection and error correction, but it also influences other conscious cognitive activities as well.

The integration of feedback information with other information about the response (e.g., corollary discharge and program selection criteria), both of which are in the STS, serves as the basis for the learner's establishment of performance expectancies and causal attributions. These cognitive motivational factors have a greater influence on motor learning and performance than previously acknowledged. Although feedback is often quantitative information about errors in performance, feedback may also be qualitative and provide information relative to the success or failure of a movement. The learner's perception of and interpretation of this qualitative information will lead to inferences about the present and future performances.

Based on the learner's attributions for a performance, shifts in expectancy formation will occur. The typical shift is that expectancies for success will increase following a successful performance while these same expectations will decrease following failure. This conclusion was reached by several researchers (see Weiner, 1974, for a review) and shifts in expectancies of success have been related to stable attributions (Weiner, Nierenberg, & Goldstein, 1976).

The relationship between stable attributes and future expectancies of success is the preferred pattern of causal inference. Similarly, if success was expected, but failure occurred, future expectations would remain high if the performance was attributed to unstable and external factors. However, if the performance was attributed to stable and internal factors, expectancies of success would decrease. If failure continued, and attributions remained stable, success would be perceived as impossible (Dweck, 1975). Therefore, the implication for any training program is to have the learner activate cognitive processes to interpret feedback so failures would be attributed to unstable and external factors, whereas success would be attributed to stable and internal causes (cf. Weiner & Sierad, 1975). In this way, the future expectancies of success would be higher and performance would be enhanced (Brickman, Linsenmeier, & McCareins, 1976) through the conscious use of feedback.

Feedback information may also be obtained through other means besides the use of conscious cognitive processes. Outcome information may be received by a learner through a non-conscious means of control, depending on the depth, or level at which one investigates the mechanisms and control processes involved. At the level of analysis which we are investigating, a learner applies conscious cognitive processes to direct the transmission

of feedback within the system during skill acquisition. At a different level of analysis, the learner's use of feedback may involve the implementation of the gamma-efferent, or spindle receptor, system to control the execution of the motor program (Keele & Summers, 1976; Klapp, 1976), and this control may become refined with the development of skill. The refinement of the lower, non-conscious level of feedback control may serve as a partial explanation of the performance differences between beginners and highly skilled performers, as well as account for the apparent automaticity in the execution of skilled movement.[2]

Through previous experience and practice, the execution of skilled movement becomes automated. The degree of automation is related to the level of conscious control required by the organism. Thus, the more "automatic" a movement becomes, the less need there is for conscious involvement by the learner. As a result, less conscious

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[2]It should also be pointed out that deafferentation techniques do not permit the learner to use sensory feedback during the performance of a skill (see Kelso & Stelmach, 1976, and Taub, 1976, for reviews), but reasonable movement can occur, based on previous information feedback stored in the long-term memory. These movements are crude and can approximate the skill to be performed.

control leads to faster processing of other incoming information. Thus, feedback can affect motor performance at both a conscious, cortical level, and at a subconscious, spinal level, both of which contribute to motor learning and motor control.

The influence of feedback on subsequent performance is an integral part of motor behavior. Motor programs are modified and updated based on the information provided by the feedback display. Feedback is a major determinant in the learning process. A learner who can make use of outcome information continuously increases the sophistication of the stored referents for movements which leads to the establishment of higher pertinence values in the LTS. These processes then aid the functions of other mechanisms in the system. With increased learning and higher pertinence values comes an increase in anticipation skills and a decrease in processing time. Additionally, since the system is prepared for the receipt of certain information, the arrival of that information leads to the learner increasing performance expectancies of success. The expectancies are related to attributions about the performance, which in turn, influence subsequent expectancies. Therefore, the feedback information constantly fulfills its roles of facilitating error detection and correction (motor program modification), learning, goal-image formation, expectancy formation, and patterns

of causal inference.

In summary, then, the learner is able to use feedback information to: (1) stimulate the peripheral organs to regulate ongoing behavior; (2) adapt behavior to situational demands; (3) activate or to lower emotions; and (4) evaluate the performance through the formation of attributions. Therefore, the enormous contribution of feedback to motor learning must be considered if an instructional program is to be successful.

Model Overview

Mechanisms and processes with unique considerations for motor behavior have been systematically identified in a model of the human behaving system. The complex sequential and parallel cognitive operations a learner uses to acquire, to select, and to execute a motor response have been described at both pragmatic and theoretical levels. Skilled performance occurs as a result of the serial or simultaneous flow of information through the mechanisms of the system, whereas an inefficient performance can be attributed to a functional deficiency somewhere in the system. Therefore, it would be instructive to briefly summarize the processes of information transmission that lead to efficient learning and skilled performance.

Information must be transmitted through the system for effective learning to occur. Inputs are received

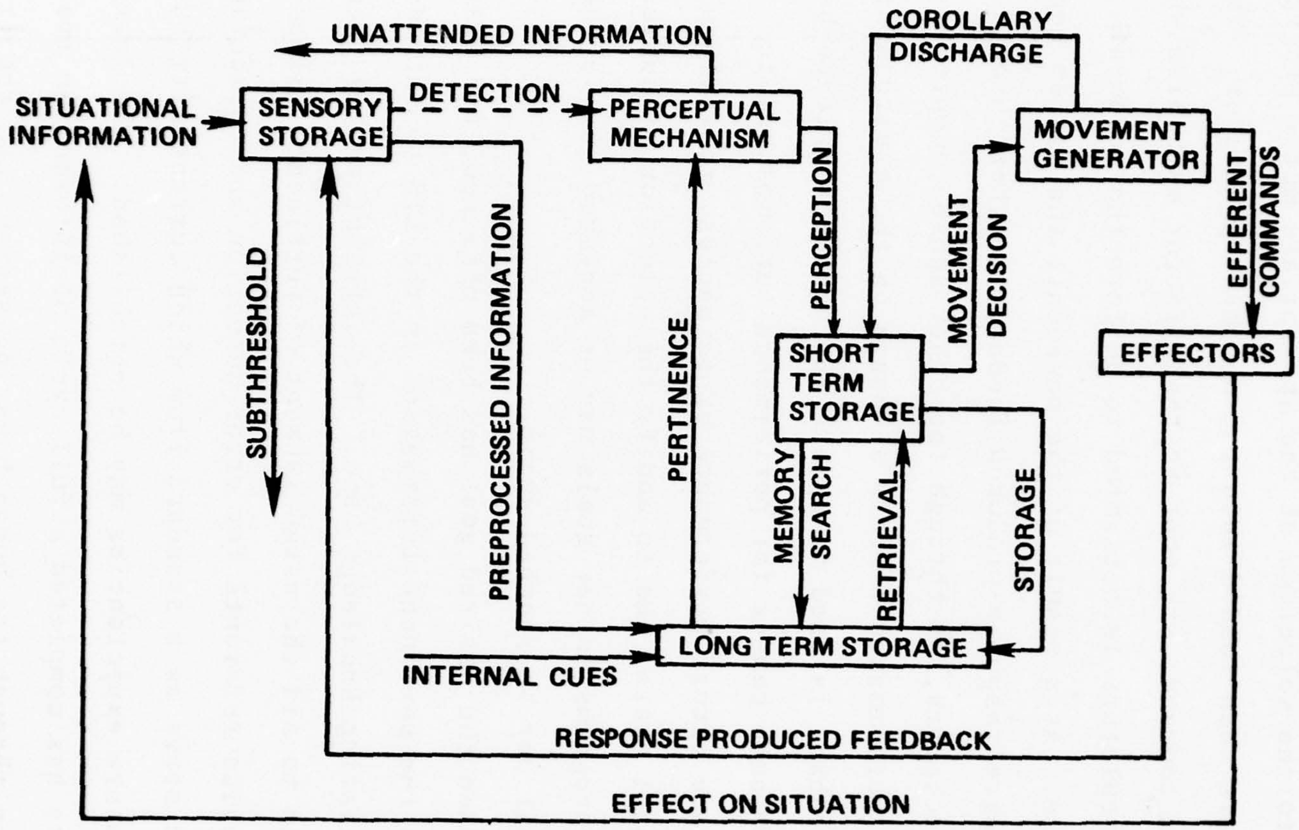
and briefly retained in the sensory stores. If the response can occur without further processing, then the stimuli need only be detected by the perceptual mechanism before the inputs are forwarded deeper into the system. In contrast, if stimuli require more elaborate processing, the inputs are sent to the LTS to contact previously stored representations and to establish a pertinence value. The pertinence value alerts the perceptual mechanism to anticipate the arrival of information in a sequential, priority order based on the degree of familiarity acquired during contact with the LTS.

Information in the perceptual mechanism is recognized by the learner, who then begins to apply meaning to the inputs. When the inputs are perceived, they are transmitted to the STS where all active processing occurs. Through the STS, the learner is able to rehearse information for temporary maintenance or future storage, to search and to retrieve additional information from the LTS, to make decisions about movements, and to select motor programs which will effectively achieve the desired goal. These cognitive processing operations serve to make the STS the primary mechanism in the human behaving system. However, it must be remembered that the STS is a limited capacity mechanism, and to require too much processing would overload the system.

Information that has been processed effectively

leads to the selection of the appropriate motor programs, which are then loaded into the movement generator. The program commands are sent to the effector mechanism where the musculature is activated to perform the movement sequence. As a result of the movement, the system begins to receive response-produced feedback, either through the proprioceptors, or through the other sense receptors as the performance effects a change on the environment. The feedback is used to update the stored knowledge base, to attribute causes for performance outcomes and to influence future performance expectancies, to influence emotional state, and to modify the selection of subsequent motor programs so new goals may be achieved, or so the old goal may be reached again.

When the desired goal has been obtained, the learner stores the pertinent information in the LTS to increase the existing knowledge base. The information may then be used to aid the establishment of pertinence values, to provide referents for error detection and correction, and to serve as a standard from which current attributions and future expectancies may be established. The learning process has completed a full cycle of information transmission through the human behaving system, and the trainee is ready to encounter new situations. Figure 9 contains the entire model.



A CONCEPTUALIZATION OF INFORMATION PROCESSING AND MOTOR BEHAVIOR

Figure 9
The Human Behaving System: Mechanisms and Control Processes Associated with the Transformation and Transmission of Information

Future Directions

Utility of the Model

The conceptual model of the human behaving system, with its unique considerations for motor behavior, is an attempt to describe cognitive processes that operate within hypothetical mechanisms during the acquisition of skill. In previous models of motor behavior (e.g., Schmidt, 1975; Welford, 1968), learning has been viewed in a sophisticated, theoretical framework with little acknowledgement given to utility and practical applications. However, the model proposed in this report was designed to accentuate the practical utility of theoretical constructs.

The potential usefulness of a model of motor behavior lies in its ability to allow adequate descriptions and explanations of scientific data, as well as its ability to "bridge the gap" between research and practical concerns. Practical considerations that might evolve from the model include instructional techniques, strategy choice and information processing mechanisms and capabilities, and the readiness state of a learner to learn/perform. The present model of the human behaving system was designed to address these kinds of problematical areas, and indeed they will be considered in future reports from our laboratory.

Mechanisms in the system through which the flow of information progresses have been described. These

hypothetical structures in the central nervous system permit the identification of the "location" of cognitive processes which a learner may activate during skill acquisition. The distinguishing feature of any conscious cognitive activity is that the learner is able to self-generate and to invoke any process that is deemed appropriate for the situation. The cognitive processes actually govern and control the transmission of information within and between the mechanisms of the system. Therefore, the learner is responsible for the processing activity that manages the transmission of information and leads to complex movement behavior.

A learner rehearses, elaborates, and organizes information through the use of acquisition strategies. The strategies are techniques the learner uses to manipulate information in order for it to become more meaningful for use in present and future situations. Thus, a direct relationship among strategies, cognitive processes, and mechanisms can be identified based on the description of the model of the human behaving system.

Within the restrictions of the model, the following relationships can be realized. As a learner enters a particular situation, potential alternative strategies may be activated to deal with available information. The learner has a choice in the possible methods for processing information at different stages of its transmission. The particular strategy that is chosen corresponds to and

influences the activation of a cognitive process, which regulates the activities performed on the information at a particular point in time. It is then quite easy to associate the cognitive process with a corresponding mechanism, as the locations and the functions of the mechanisms in the human behaving system have been previously described.

The strategy-process-mechanism relationship does possess practical implications for instructors. A knowledge of task requirements would enable an instructor to determine the alternative strategies that would best lead to the achievement of the goal. Subsequently, the cognitive process that would control these strategies would be activated to regulate the transmission of information. An instructor would then be able to identify the dominant processing mechanism that a learner must use to acquire the skill.

An example of the proposed relationship involves the act of hitting a pitched baseball. The task goal has been determined, and the learner needs a strategy that will facilitate the accomplishment of the task. Since concentration is a key factor in batting, the learner decides to focus attention to a narrow stream of inputs, mainly the location of the ball. The cognitive process which is activated is selective attention, and the dominant mechanism for this task is the perceptual

mechanism. The example can also be depicted diagrammatically:

task	hitting a baseball
↓	↓
strategy	narrow focus (concentration)
↓	↓
cognitive process	selective attention
↓	↓
mechanism	perceptual mechanism

The practical contribution that can be derived from the model is the identification of the proposed strategy-process-mechanism relationships for any psychomotor task that might be learned. Presently, strategy and task classification schemes are being developed that can facilitate the determination of these relationships. The schemes will serve as a foundation for the implementation of instructional methodologies that will ultimately lead to the learner's ability to identify and generate strategies appropriate for categories of tasks.

Future Research

Three major concerns will permeate our future research efforts. Interest will be focused on the rate of skill acquisition through the use of various strategies, the ability of a learner to transfer the use of an optimal strategy to the acquisition of a new, but related motor skill, and the manner in which the use of strategies for skill acquisition will aid the learner's long-term retention of that skill when it must be performed at a later date. When these goals are realized at the conclusion of the

experimental phase of the project, we will develop self-administered instructional materials (learner modules) that cover the learning of learning strategies for psychomotor tasks. These modules will be field tested to determine their effectiveness, and to replicate the results of the laboratory work.

The major question which we will address is how to improve the storage and the retrieval capabilities of trainees. We have identified alternative rehearsal, attention, labeling, and imagery strategies to enhance the transformation of response and display information. We plan to investigate their relative effectiveness on present task learning and transfer to similar tasks. Furthermore, of interest is the release or retrieval of information from storage, the loading of a motor program to a movement generator, and the correct decisions concerned with cost-benefits as well as program selection and execution. Studies are being designed and conducted to resolve issues on this topic.

Finally, the more effective use of response-produced feedback in the acquisition of skill will be evaluated with learner strategies geared to improve the interpretation and analysis of information, the formation of attributions, and the establishment of expectancy levels of achievement. Since skills learning, in contrast to the study of verbal material, involves continuous overt

performance, we can design studies to monitor continually the feedback available, how it is used, and how alternative strategies work to benefit the learner. Once again, we are primarily interested in the establishment of strategies in learners that they will apply to future related learning and performing situations.

The content of each of our experiments is <u>not</u> designed to improve the acquisition of specific motor skills. Rather, we are seeking to develop methods which will enable learners to <u>self-generate problem-solving strategies</u> and techniques in order that skills may be obtained more rapidly. The development of analytical and adaptation processes within a learner will lead to the creation of self-instructional environments. If the trainee possesses the strategies and skills to produce a solution to a problem, then the amount of external guidance necessary for learning is reduced. Additionally, the acquired skill is probably retained to a greater degree since the learner was more involved in the learning experience.

We hope to continually bridge the motor and verbal learning areas, as there are many human mechanisms and processes that operate similarly for all behaviors. Although we will be analyzing ways of improving performance in motor behaviors, many findings should be applicable to verbal behaviors. These results will also be

beneficial to military, occupational, and educational training programs.

The ultimate goal of our research is to have learners develop the capabilities to generate strategies for skill acquisition (to adapt, accommodate, trouble-shoot, problem solve). Although the project is a difficult one, we plan to continue at a rapid pace to accumulate a vast array of produced resources, to contact human resources, and to organize, to synthesize, and to develop the materials to meet the needs of the project. We hope that our initial work has provided some clarification of the internal processes which may occur during motor skill acquisition, and that our future work will prove our hypotheses and validate our assumptions.

Summary

A brief description of the historical development of motor skills research has been provided. The early efforts appeared to be loosely structured without a theoretical framework upon which investigations were based. This led to the formulation of models which served as descriptors of human behavior. From these models and research in various fields of endeavor, we developed an integrative human behaving system model. The human behaving system was described along with its unique considerations for motor behavior. However, the

nature of the model, with a heavy emphasis on cognitive processes, also allows it to be applicable to verbal behavior.

The present model has served as a guide for the identification of various strategies a learner may use to enhance the processing effectiveness of particular mechanisms. An increase in processing effectiveness should lead to a more rapid rate of skill acquisition and to a greater potential for transfer of processing capabilities to similar, but related tasks. Several experiments are being conducted in order to test these assumptions.

The experiments have been designed to determine the generalizability of strategy usage across categories of psychomotor skills, as well as the relationship between strategies and tasks. These research efforts are leading to the formulation of strategy and task classification schemes based on the mechanisms and cognitive processes described in the model of the human behaving system. The functional utility of these classification schemes is readily apparent. Instructional designers will be able to provide learning environments in which a learner can make optimal use of individualized cognitive strategies to acquire many tasks in a short period of time. Furthermore, learners and instructors will have the opportunity to determine similarities among

tasks and methods of acquisition through these classification schemes, so that the rate of learning will be increased.

The model of the human behaving system provides an understanding of the processes that interact to produce skilled behavior. The model has both practical (for instructional purposes) and theoretical (for research purposes) utility. The development of this conceptual framework was viewed as a necessary first step to facilitate research efforts in (1) identifying the role of cognitive processes in the acquisition of motor skill, and (2) suggesting alternative strategies that learners might use to improve the efficiency and effectiveness of these processes.

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